Technical Report R 355

PROTECTION OF MOORING BUOYS – PART V. FOURTH RATING INSPECTION

4 January 1965

U. S. NAVAL CIVIL ENGINEERING LABORATORY
Port Hueneme, California

PROTECTION OF MOORING BUOYS — PART V. FOURTH RATING INSPECTION

Y-R007-08-04-404

Type C

by

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ABSTRACT

This is the fifth of a series of reports on the protection of mooring buoys. Fourteen test buoys were given their fourth rating for extent of coating deterioration, corrosion of steel, and fouling. A fifteenth buoy had been removed from test at the time of the fourth inspection because of its advanced deterioration. The coating systems on eight of the buoys were in good condition and the six other coating systems showed varying degrees of moderate deterioration. Two sets of thirteen test panels coated with the different coating systems used on the buoys were given their third rating inspection after 18 months of exposure. One set was exposed in San Diego Bay and the other in Port Hueneme Harbor. The condition of the coating systems on Port Hueneme test panels showed a general correlation with those on San Diego test panels and buoys. In addition to environmental deterioration on buoys and test panels, the buoys were abraded by mooring naval vessels. The galvanic corrosion of rivet heads observed on most of the Mark I buoys during the last inspection had not worsened to any significant extent. On those buoys with an antifouling coat, very little antifouling protection remained after 20 months, but on the test panels two antifouling coatings were still retarding fouling after 18 months.

Three of the test buoys were cathodically protected with a system using a sacrificial magnesium anode, a control head, and a remote ground cable. Although the potentials produced on these buoys by this system were outside of the range desired for complete protection, the system allowed only light rusting and no pitting. When the system on each of these buoys was modified by replacing the magnesium anode with a zinc anode united directly to the ground cable, potentials reached the desired magnitude.

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The Laboratory invites comment on this report, particularly on the results obtained by those who have applied the information.

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INTRODUCTION

Because the presently specified coatings for mooring buoys have performed unsatisfactorily, the Bureau of Yards and Docks assigned the Naval Civil Engineering Laboratory to find or develop better corrosion protection for fleet mooring buoys. The assignment included protective coatings and cathodic protection.

A field test program was initiated in San Diego with fifteen peg-top riser-chain mooring buoys (Mark I or Mark II). Thirteen different coating systems were used, and a cathodic protection system was installed on one buoy of each of three pairs used in this part of the test program. The results of the program are published in a series. Technical Report R-246,[1] the first in the series, described the application of protective coatings and the installation of the cathodic protection system. Technical Report R-258,[2] the second in this series, described the condition of buoys and coatings at the time of their first rating inspection. Technical Report R-291,[3] the third in this series, described their condition at the time of their second rating inspection, and the condition of sets of steel test panels coated with the same protective coatings applied to the buoys, after 6 months of exposure in either San Diego Bay or Port Hueneme Harbor. Technical Report R-314,[4] described the condition of the buoys at the time of their third rating inspection and the condition of the panels after 1 year of exposure. This, the fifth report, describes the condition of the buoys at the time of their fourth rating inspection and the condition of the panels after 18 months of exposure.

SERVICE CONDITIONS

Fifteen test mooring buoys were placed in an area of North San Diego Bay that receives heavy service from the fleet. Some of the buoys were badly damaged by overriding vessels and by the abrasion of mooring lines and securing assemblies.

Because it was necessary to place the test buoys in service a few at a time, and because there were long delays in obtaining acceptable specification coatings, the test buoys were placed in service over a considerable period of time. One set of thirteen panels was suspended from a pier in San Diego Bay and the other from a pier in Port Hueneme Harbor. A portion of each panel was continually submerged, another portion was subject to tidal changes, and a third portion was continually exposed to the atmosphere. The panels were not exposed to their harbor environments at the same time as the buoys. They were kept in storage until all of them had been coated, and then were all placed in test at the same time, rather than over a 6-month period as were the buoys. At the time of their third rating (described herein), they had been exposed for 18 months.

INSPECTION PROCEDURE

Each of the test mooring buoys was inspected after it had been lifted onto the deck of a floating crane. The amount of fouling was determined, the types of organisms were recorded, and fouling damage to the coating was noted. Two independent ratings of the condition of each buoy and its protective coating system were made in the atmospheric, splash, and submerged zones. After the fouling was examined, the cone and splash zone of each buoy were washed with a high-pressure stream of sea water to remove the fouling and expose any coating damage.

To determine the amount of additional potential produced on cathodically protected buoys, electrical potential measurements were made on buoys with and without cathodic protection. The coating deterioration and corrosion damage of the three cathodically protected buoys was compared to that of the control buoys.

Two independent ratings were also made of the condition of the coating systems on the steel test panels exposed in San Diego Bay and Port Hueneme Harbor. Fouling organisms were carefully removed from one side of each test panel with a wooden scraper and a stiff brush before rating the coating condition in the fouled area.

RATING CRITERIA

As far as possible, the methods of rating the coatings on buoys and test panels were those published by the American Society for Testing and Materials.[5] These published methods define the conditions rated and give photographic reference standards. Thus, chalking, blistering, checking, cracking, flaking, erosion, and rusting were rated from 0 to 10 by ADTM methods D-659-44, D-714-56, D-660-44, D-661-44, D-772-47, D-662-44, and D-610-43, respectively. A rating of 10 usually describes a perfect condition, and a rating of 0, a completely deteriorated condition. Blistering frequency was rated as none (N), few (F), medium (M), medium dense (MD), or dense (D). Surface area covered by fouling (plant, animal, or combined fouling) was rated from 0 (100 percent covered) to 10 (0 percent covered). Color of the topcoat on the b[illegible] was also rated from 0 to 10; 10 indicates pure white with no yellowing [illegible] discoloration (except rust streaks from uncoated bolts), and 0 indicates a color unacceptable to the U. S. Coast Guard.

Frequency of use of buoys by the fleet was rated as light (0 to 2 days per week), medium (2 to 4 days per week), or heavy (4 to 7 days per week). Two types of moorings were made to the buoys. Some provide bow and stern moorings only, and the rest provide either bow and stern or free-swinging moorings.

The overall condition of each buoy and its coating system was rated as excellent (in essentially the same condition as when first placed in service); good (very minor deterioration); fair (a significant amount of coating deterioration and/or rusting but still in serviceable condition); poor (coating deterioration and rusting serious enough to lead to an early removal from service).

The coating system on each test panel was given an overall rating from 0 (minimum) to 10 (maximum) depending upon both the condition of the entire coating system and the protection afforded to the steel. It was much easier to rate the overall coating conditions on the panels than on the buoys because the panels were not abraded in mooring service.

CONDITION OF BUOY COATINGS

Table I describes each coating system. The overall ratings and lengths of service of buoy coatings are summarized in Table II. The proprietary sources of the coatings tested are listed in References 2 through 4. Ratings of specific conditions of coated test buoys are given in Appendix A.

Coating System 1: Urethane

The buoy with Coating System 1 had deteriorated only slightly more since the previous inspection.[4] The galvanic corrosion of rivet heads had not increased significantly. The patches of underwater-curing epoxy that had been applied to underwater abraded areas 18 months before (Figure 1) were still in relatively good condition. On a few of these patches, where lifting of the edges from the coating was previously noted,[3,4] a portion of the lifted edge had been chipped off by abrasion. In no case, however, was there loss of epoxy where it was bonded directly to the steel. The epoxy patches were still fully protecting the steel previously exposed when the coating was damaged. An underwater portion of the buoy had been abraded since the previous inspection, and the exposed steel was rusting. The bare steel was cleaned by power wire brushing, and the surrounding undamaged coating was scrubbed with a stiff brush. The cleaned metal and one inch of the surrounding coating were covered (Figure 2) with the underwater-curing epoxy[2] previously applied to this buoy.

There was more fouling on this buoy than on the others, but the organisms were similar. Barnacles, mussels, and green algae were present in the splash zone; tunicates, barnacles, hydroids, bryozoa, mussels, and tube worms were present in the submerged zone. Specific species of fouling organisms identified on test buoys were listed in TR-291.[3] None of the coating systems in good or good-fair condition were damaged by fouling.

Table I. System Description and Coating Thickness

System		Primer			Additional Coats			Total Thickness (mils)
Number	Description	Type	Coats (No.)	Thickness (mils)	Type	Coats (No.)	Thickness (mils)	
1	Urethane	Urethane	1	2	Urethane	3	8	10
2	Epoxy	Epoxy	1	4-5	Epoxy Epoxy Antifouling	1 1 1	4 3 4	8-9 11-12 15-16
3	Epoxy Polyester	Epoxy		4-5	Polyester Antifouling	2 1	5-6 4	-11 13-15
4	Epoxy - Coal Tar Epoxy	Epoxy	1	4	Coal Tar Epoxy Epoxy Epoxy	1 1 1	4-5 4 4	8-9 12-13 16-17
5	Coal Tar Epoxy - Phenolic	Coal Tar Epoxy	1	5	Phenolic Phenolic	1 1	4-6 6-7	9-11 15-18
6 & 6A	Phenolic Mastic	Mica-filled Phenolic	1	10-11	Phenolic Mastic	1	8-9	18-20
7	Phenolic	Wash Primer Phenolic	1 2	4	Phenolic Antifouling	1 1	2-3 3	7-8 8
8	Phenolic Alkyd	Wash Primer Phenolic	1 2	4	Alkyd Antifouling	1 1	2-3 3	7-8 8
9	Vinyl	Wash Primer Vinyl	1 4	6-7	Vinyl-alkyd Antifouling	3 2	4 4	11-12 11-12
10	High-Build Vinyl	Vinyl	1	2	Vinyl Vinyl	2 1	5-6 2	7-8 9-10
11	Vinyl Mastic	Vinyl Phenolic	1	1-2	Vinyl Mastic	2	12-13	13-15
12	Inorganic Zinc Silicate Vinyl Mastic	Inorganic Zinc Silicate Vinyl Phenolic	1 1	4 1-2	Vinyl Mastic	1	5-6	10-12
13 & 14	Saran Formula [illegible]	—	—	—	Saran	8	8	8

Table II. Overall Rating and Length of Service for Coated Buoys

Coating System		Length of Service (days)	Overall Rating
Number	Description		
1	Urethane	787	good
2	Epoxy	747	good
3	Epoxy - Polyester	747	fair
4	Epoxy - Coal Tar Epoxy	787	good-fair
5	Coal Tar Epoxy - Phenolic	746	fair
6	Phenolic Mastic	745	good
6C	Phenolic Mastic	746	good
7C	Phenolic	599	good
8	Phenolic - Alkyd	600	good
9	Vinyl	622	good
10	High-Body Vinyl	713	fair
11	Vinyl Mastic	—	removed from test
12	Inorganic Zinc Silicate - vinyl Mastic	787	fair
13	Saran	746	good-fair
13C	Saran	753	good

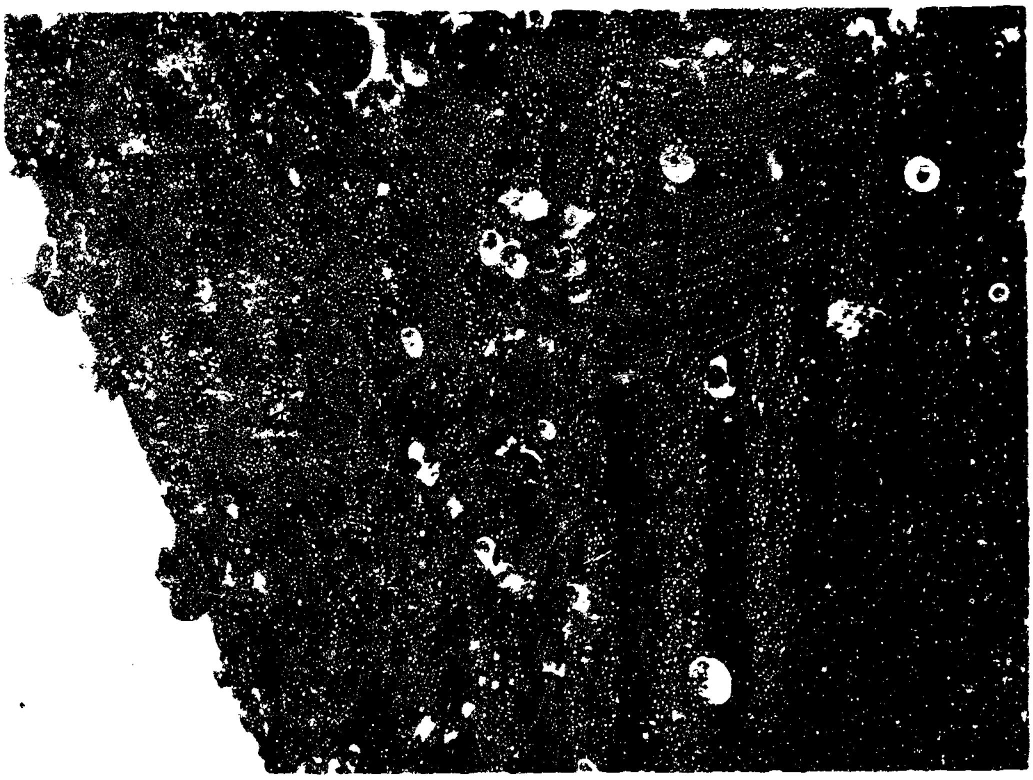

Figure 1. Underwater-curing epoxy patches (see arrows) on System 1 buoy. Note fouling still clinging to patches after high-pressure hosing.

Figure 2. Patching damaged area of System 1 buoy with underwater-curing epoxy.

Coating System 2: Epoxy

The buoy with Coating System 2 had very little coating deterioration (Figure 3). The slight rusting in the atmospheric zone was restricted to areas abraded by the securing assembly; that in the submerged zone was restricted to a few rivet heads. A dent had been knocked into one of the steel plates in the submerged zone, but this did not damage the coating.

Coating System 3: Epoxy-Polyester

The buoy with Coating System 3 was in essentially the same condition (Figure 4) as at the previous inspection. The yellow epoxy primer was continuing to protect the steel from corrosion in areas where much of the polyester topcoat had been lost. The side of the buoy was considerably streaked with rust from behind tack-welded flanges and from abraded areas.

Coating System 4: Epoxy - Coal Tar Epoxy

The buoy with Coating System 4 was in essentially the same condition (Figure 5) as at the previous inspection. The delamination of the topcoat and seal coat (Figure 6) had increased only slightly, and the underlying epoxy primer and coal tar epoxy were providing good protection to the steel.

Coating System 5: Coal Tar Epoxy - Phenolic

The overall condition of the Coating System 5 buoy was similar to that noted in the previous inspection. At that time there was some concern over the advanced galvanic corrosion of abraded rivet heads. These rivet heads had not lost much more metal since then. There was considerable abrasion damage on the top of this lightly fendered Mark I buoy. Some of these damaged areas had been patched with underwater-curing epoxy 18 months earlier. Several of these patches (Figure 7) had been partially chipped away by further abrasion from the securing assembly.

Coating Systems 6 and 6C: Phenolic Mastic

Coating Systems 6 and 6C were identical, but the 6C buoy was cathodically protected. The abraded top and rivet heads (Figure 8) in the submerged portion of the System 6 buoy had not deteriorated significantly further since the last inspection. A year before, the System 6C buoy had been rather extensively abraded by a ship; these abraded areas continued to show rusting but no pitting either above or below (Figure 9) the water line.

Figure 3. System 2 buoy after removal of fouling.

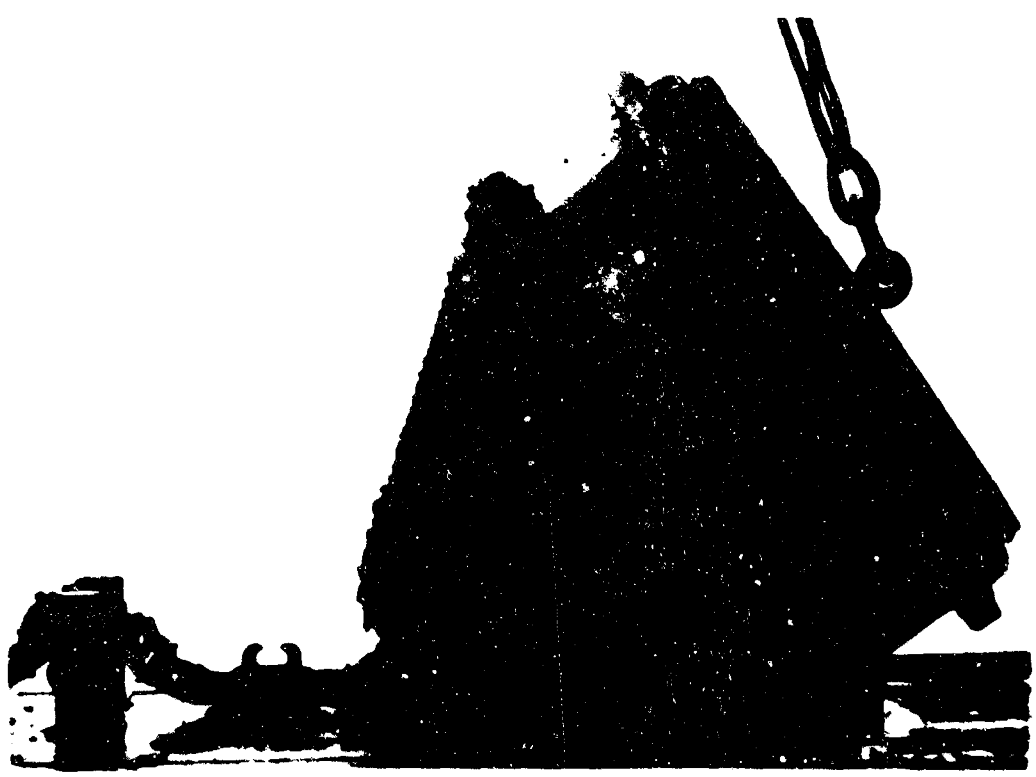

Figure 4. System 3 buoy after removal of fouling.

Figure 5. System 4 buoy after removal of fouling.

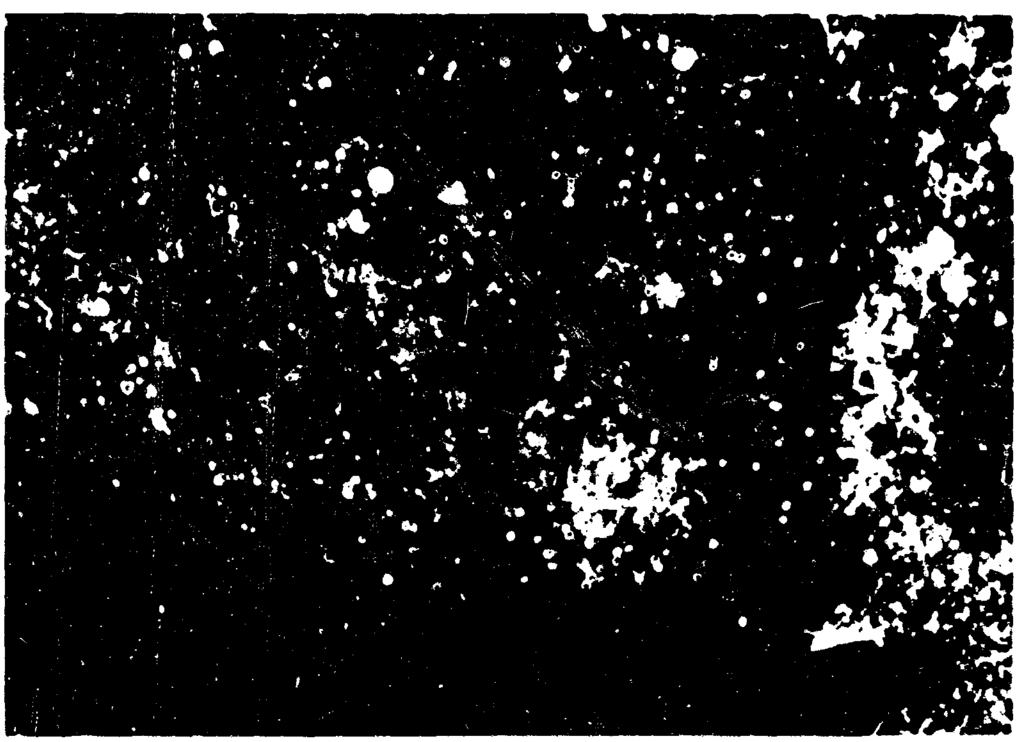

Figure 6. Delamination area of System 4 buoy. Note fouling on the coal tar coating, even though the coating is providing good protection to the steel.

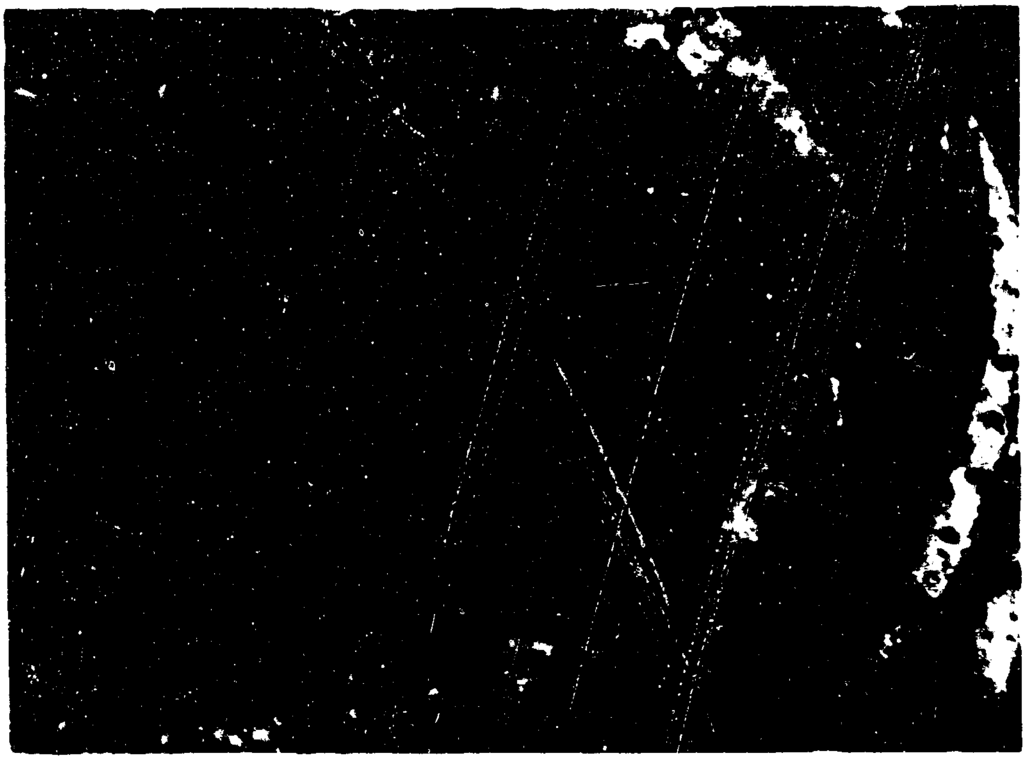

Figure 7. Top of System 5 buoy. Note abrasion of coating system and epoxy patches.

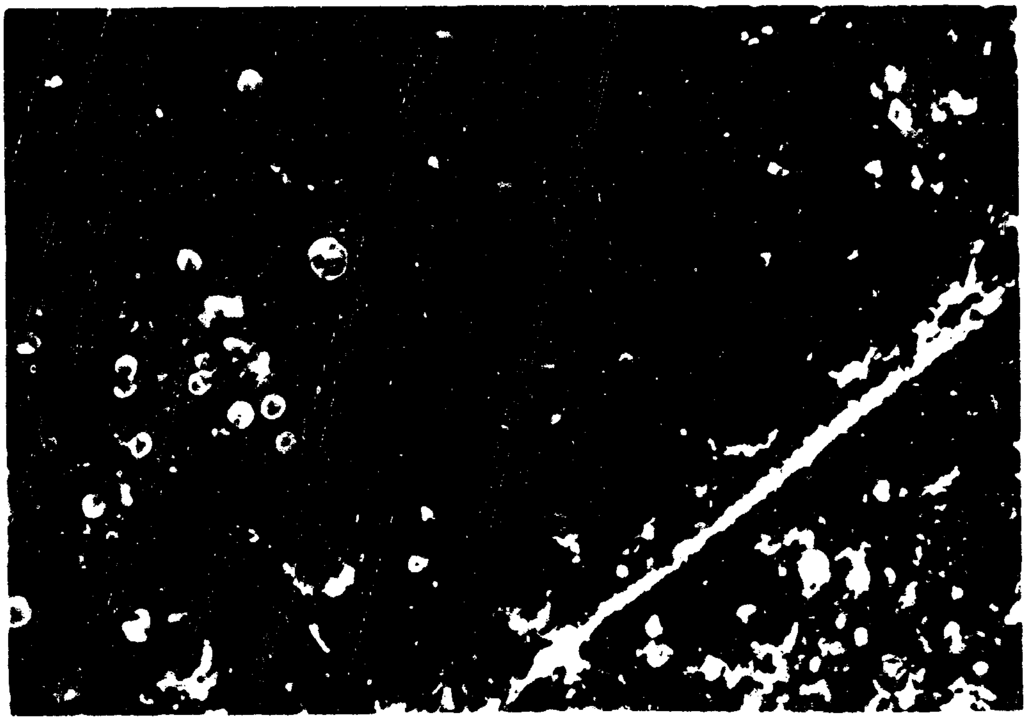

Figure 8. Riveted seam of System 6 buoy showing abraded rivet heads with galvanic corrosion.

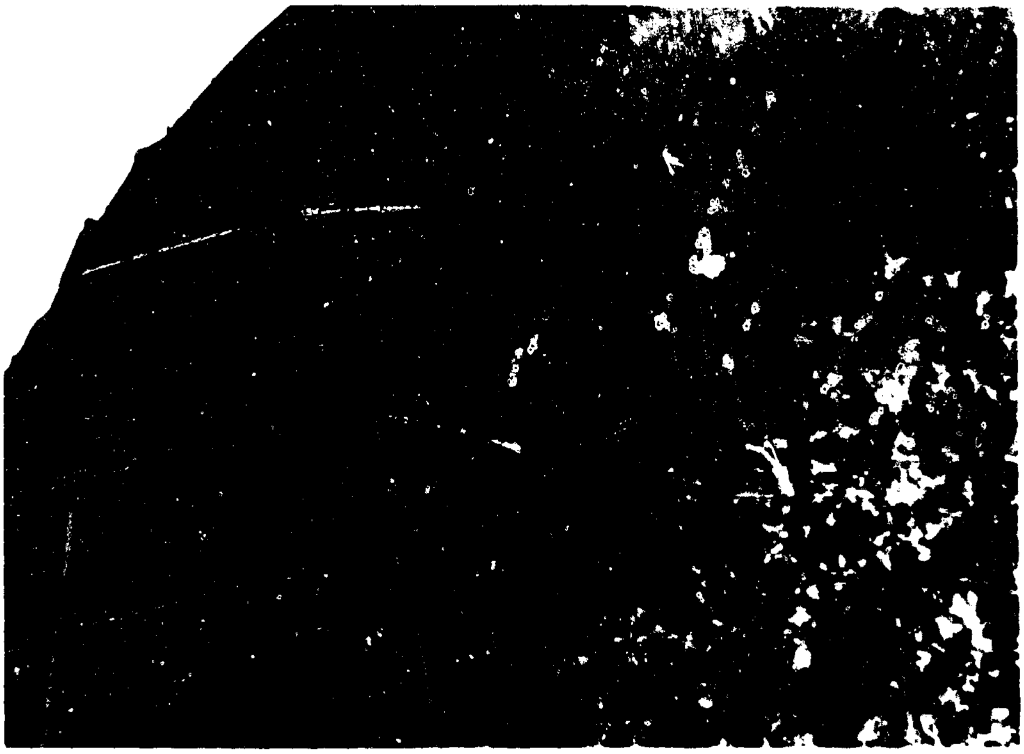

Figure 9. Abraded underwater portion of System 6C buoy.

System 7C: Phenolic

The fouling on the Coating System 7C buoy (Figure 10) was of a type and intensity similar to that on test buoys without antifouling paint. Growths of barnacles and tunicates were relatively heavy, and there were mussels, hydroids, green algae, and tube worms to a lesser degree. The yellow primer had been exposed in many places on the submerged portion of the buoy where the antifouling paint had eroded, but this had not permitted any rusting. The pin-point rusting previously noted[4] in the atmospheric and splash zones had not advanced significantly since the previous inspection.

System 8: Phenolic-Alkyd

The coating system on the submerged portion of the System 8 buoy (Figure 11) was identical to that of the System 7C buoy. Consequently, the fouling on both buoys was similar. The System 8 buoy, however, had lost less antifouling coat, so less yellow primer was exposed. The pin-point rusting and abraded areas previously noted on the buoy[3,4] showed no further significant corrosion since the previous inspection.

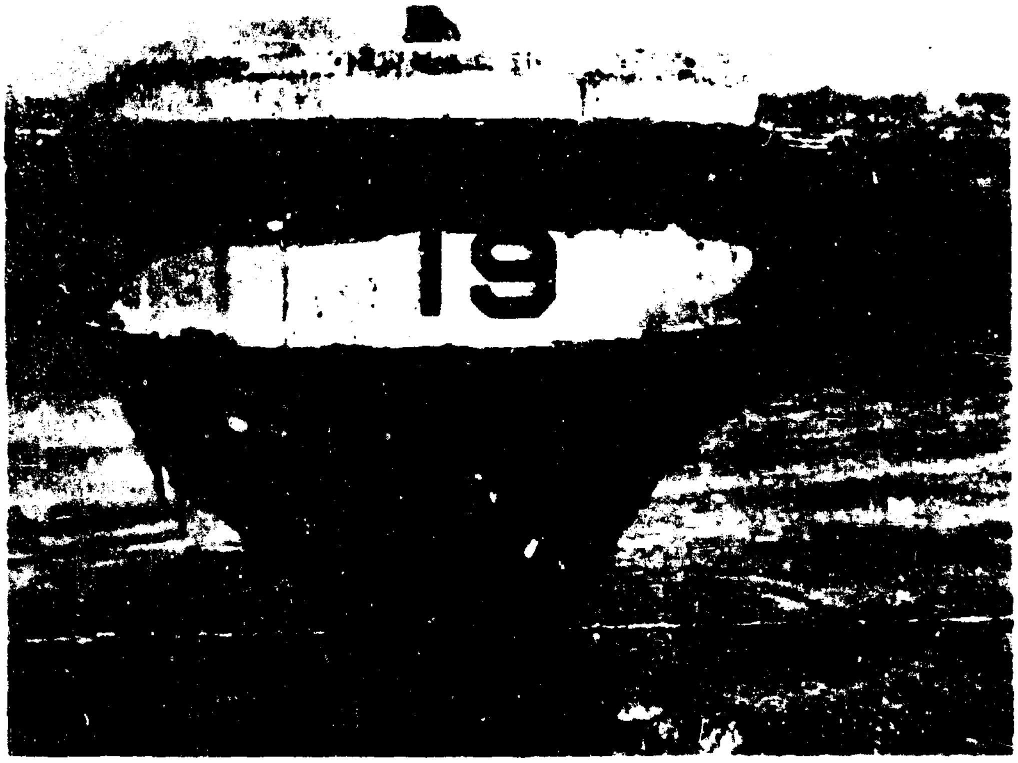

Figure 10. System 7C buoy before removal of fouling.

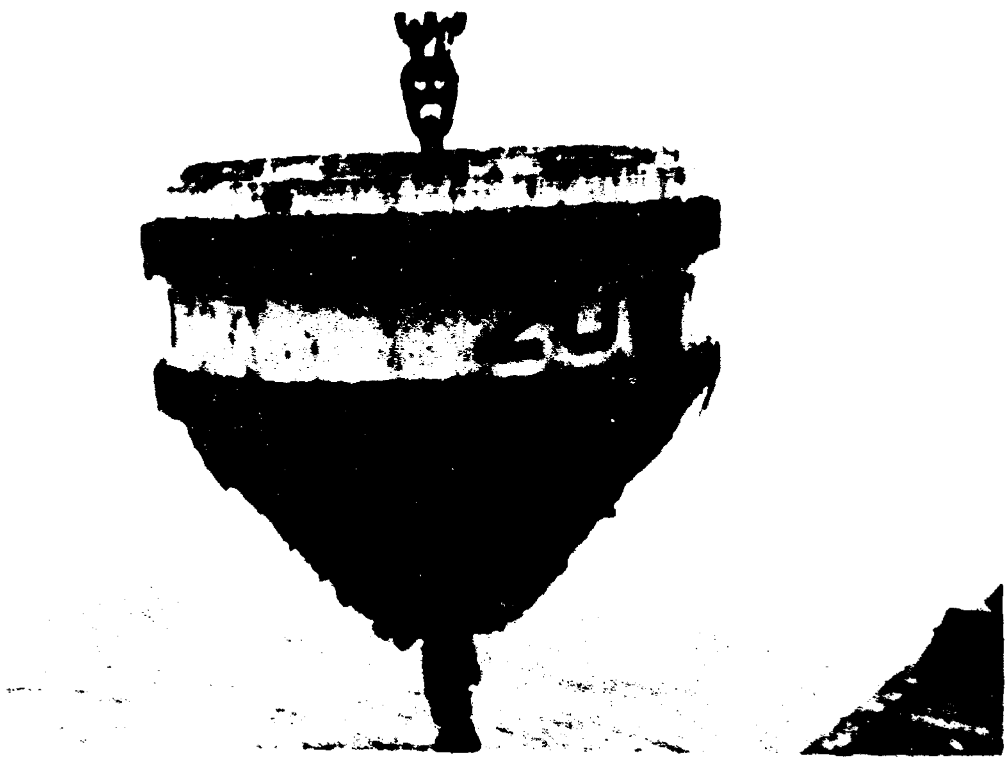

Figure 11. System 8 buoy before removal of fouling.

Coating System 9: Vinyl

The amount of fouling on Coating System 9 buoy (Figure 12) was medium. The heavy growth of green algae was due to the fact that the Mark I buoy rode lower in the water than did the Mark II buoys (Systems 7C and 8). Other fouling organisms on these three buoys were identical in species. When the System 9 buoy was hosed off, several small spots of vinyl primer were exposed where antifouling paint washed off with mussels.

The slight rusting caused by abrasion had not increased much since the previous inspection. A ship had dented a steel plate in the submerged zone, but this had not damaged the coating.

Coating System 10: High-Body Vinyl

The blistering and rusting in all three zones of the System 10 buoy had not deteriorated appreciably further (Figure 13) since the previous inspection. Many of the blisters were broken by the high-pressure hosing, exposing bare metal. Both fenders on the side of the buoy had been broken by the impact of a naval vessel.

Coating System 11: Vinyl Mastic

Because of advanced corrosion, the Coating System 11 buoy was removed from test at the time of the previous inspection.

Coating System 12: Inorganic Zinc Silicate - Vinyl Mastic

The Coating System 12 buoy was essentially free of corrosion in all three zones (Figure 14). The only corrosion noted was where portions of the top edge had been abraded by mooring lines. Although approximately half of the primer and topcoat had been lost from the submerged portion of the buoy after 6 months of service, the underlying inorganic zinc silicate was still preventing corrosion 18 months later (Figure 15).

Coating Systems 13 and 13C: Saran

Coating Systems 13 and 13C were identical, but System 13C was applied to a cathodically protected buoy. There was rust on both buoys (Figures 16 and 17) in the atmospheric and splash zones, either pin-point rusting or rusting initiated by coating abrasion. The System 13 buoy also had rust in the submerged zone, but in this portion of the System 13C buoy rust occurred only on the square of steel exposed by wire brushing to test the cathodic protection system. The 13C buoy had been struck by a ship that bent the cathodic protection unit, but this damaged neither the coating nor the cathodic protection system.

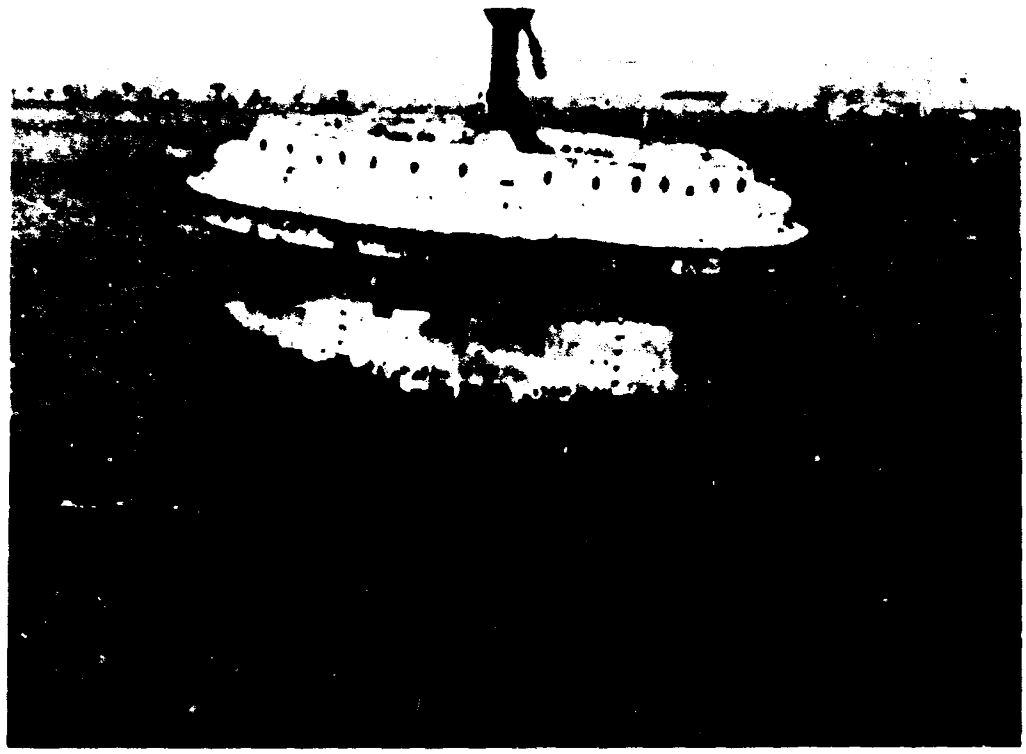

Figure 12. System 9 buoy before removal of fouling.

Figure 13. System 10 buoy after removal of fouling.

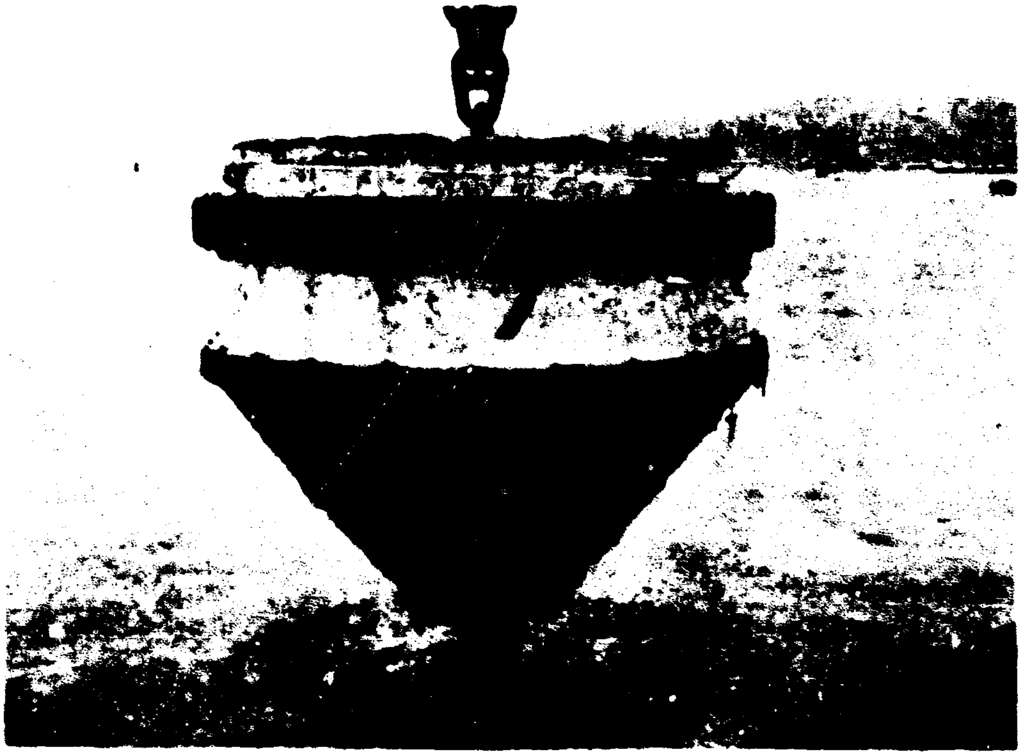

Figure 14. System 12 buoy before removal of fouling.

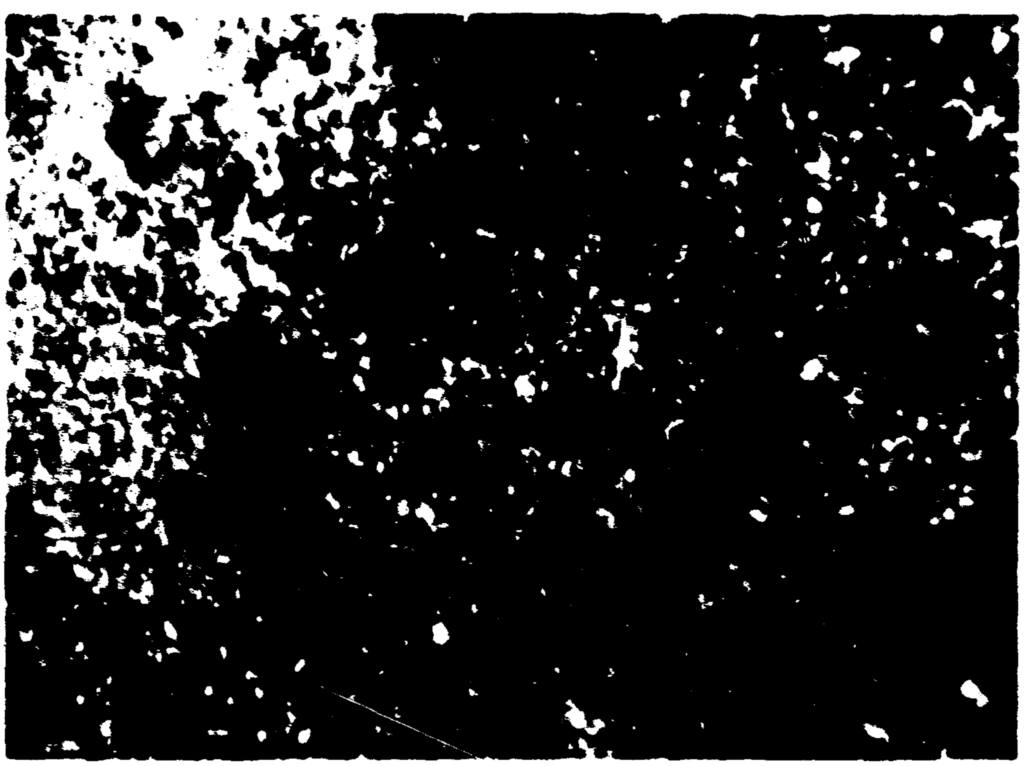

Figure 15. Deteriorated portion of System 12 buoy, showing the topcoat (white), the primer (dark brown), and the inorganic zinc silicate (gray).

Figure 16. System 13 buoy before removal of fouling.

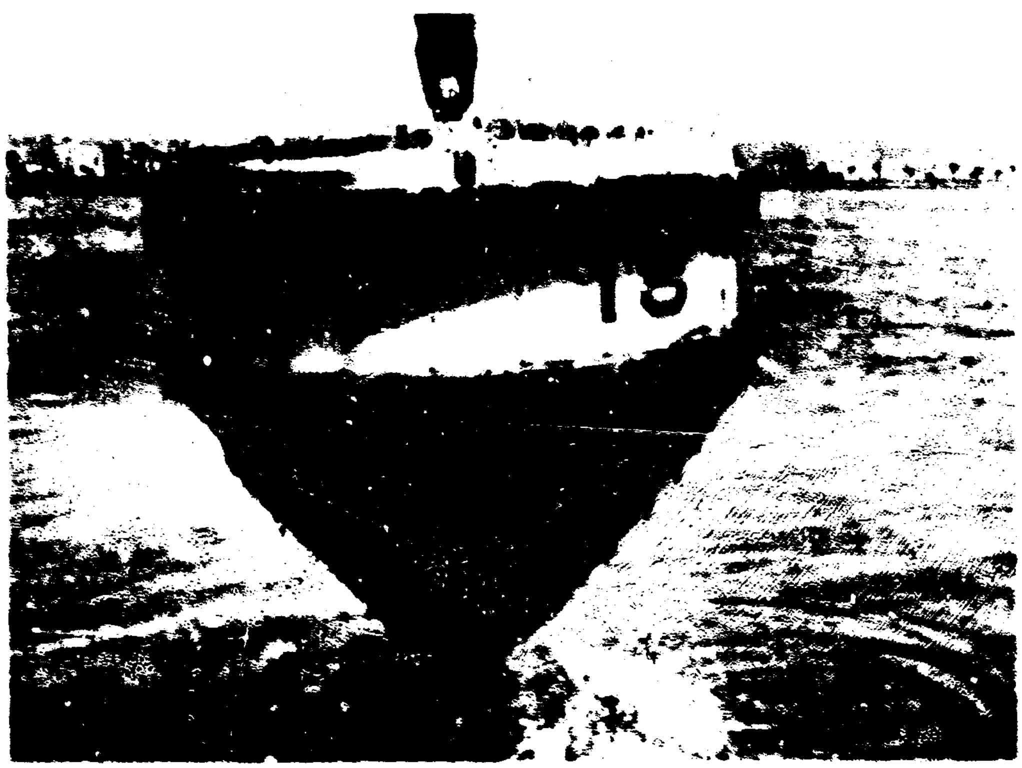

Figure 17. System 13C buoy before removal of fouling.

CONDITION OF COATED PANELS

The coating system on each test panel is rated in Table III, and the ratings of specific conditions are given in Appendix B.

Although not noted in Appendix B, numerous small shrimp were present in the fouling on all San Diego panels. These shrimp were living among the fouling organisms and not attached directly to the panels; thus, they represented no fouling problem but indicated that a change had occurred in the environment.

Coating System 1: Urethane

Both urethane-coated panels were in excellent condition. The only sign of deterioration was a few pin-point rust spots in the atmospheric zone of the Port Hueneme panel.

Coating System 2: Epoxy

Other than loss of the antifouling coating, neither epoxy panel showed any coating deterioration, and there was no rust on either panel.

Coating System 3: Epoxy-Polyester

As previously reported,[4] when the antifouling coat (identical to that of System 2) was lost from System 3 panels it took the polyester coats with it, exposing the underlying epoxy primer. This primer has continued to prevent rust on the San Diego panel and has permitted only slight rusting on the Port Hueneme panel. There was still no blistering on the San Diego panel, whereas extensive blistering was previously noted[4] on the Port Hueneme panel.

Coating System 4: Epoxy - Coal Tar Epoxy

Neither of the System 4 panels showed deterioration in any zone.

Coating System 5: Coal Tar Epoxy - Phenolic

On both of the System 5 panels, the seal coat and underlying coal tar epoxy coat gave excellent protection. The previously reported[3] loss of topcoat had no effect.

Coating System 6: Phenolic Mastic

Neither of the System 6 panels showed deterioration in any zone.

Table III. Overall Ratings[1] of Coated Panels After Eighteen Months Exposure

Coating System		Exposure Site	
Number	Description	Port Hueneme	San Diego
1	Urethane	10	10
2	Epoxy	10	10
3	Epoxy - Polyester	9	9
4	Epoxy - Coal Tar Epoxy	10	10
5	Coal Tar Epoxy - Phenolic	9	9
6	Phenolic Mastic	10	10
7C	Phenolic	10	10
8	Phenolic - Alkyd	10	10
9	Vinyl	10	10
10	High-Body Vinyl	8	9
11	Vinyl Mastic	7	8
12	Inorganic Zinc Silicate - Vinyl Mastic	9	9
13	Saran	9	9

1/ 10 = perfect condition; 0 = complete deterioration

Coating System 7C: Phenolic

The slight rusting reported[3,4] in the atmospheric zone of the Port Hueneme System 7C panel had not increased significantly, and the San Diego panel showed no deterioration in any zone. The antifouling coat was still effective in restricting the fouling to a light growth, but a slight amount of the yellow primer was showing through the black antifouling on both panels.

Coating System 8: Phenolic-Alkyd

There were a few small blisters in the submerged zone of the Port Hueneme panel but otherwise no sign of coating deterioration or rust on either System 8 panel. The antifouling coat was identical to that on 7C, and fouling was light. But here too some yellow primer was showing through the black antifouling.

Coating System 9: Vinyl

Neither System 9 panel showed deterioration in any zone. The vinyl antifouling coating continued to permit only light fouling at both locations.

Coating System 10: High-Body Vinyl

Blisters were numerous on the Port Hueneme System 10 panel, and the steel had rusted in all three zones. The San Diego panel was also blistered and rusted but to a lesser degree.

Coating System 11: Vinyl Mastic

On the System 11 panel in Port Hueneme, blistering and rusting were severe in the tidal zone, but the other zones were in comparatively good condition. There was slightly less blistering and rusting on the San Diego panel, but it occurred in both the tidal and submerged zones.

Coating System 12: Inorganic Zinc Silicate - Vinyl Mastic

The System 12 panel in Port Hueneme had a few blisters in the tidal zone where the previously noted[3,4] delamination of the vinyl mastic coating was concentrated. A similar blistering and loss of coating occurred in both the tidal and submerged zones of the San Diego panel. The underlying inorganic zinc silicate had protected both panels from corrosion.

Coating System 13: Saran

Both System 13 panels were in very good condition. Only a few pin holes of rust were noted, with some edge-rusting.

CATHODIC PROTECTION RESULTS

The original cathodic protection system[1] installed on three of the test mooring buoys utilized a sacrificial magnesium anode, a control head designed to maintain a potential near -850 millivolts (with respect to a reference silver-silver chloride half-cell), and a remote ground cable to distribute the protection throughout the submerged exterior of the buoy. Although values near the desired potential were obtained when the three cathodically protected buoys were initially installed, by the time of the second inspection the potential had fallen to -730 mv. At the same time, the potential of the buoys without cathodic protection averaged -650 mv. The rate of magnesium loss from anodes had also decreased. It appeared that resistance had developed somewhere in the circuit. The top bronze securing bracket on the control head was replaced with a steel bracket, and the contact points were sanded to remove any resistance film. But the potential increased only partially and the increase was temporary. So, at the third inspection, the original control heads were replaced with new control heads designed by the supplier to maintain a potential of -900 mv. After 2 months of service the average potential on cathodically protected buoys was only 90 mv more than on unprotected buoys.

Consequently, the cathodic protection system on the System 7C buoy was again modified. The magnesium anode was replaced with a zinc anode, and the remote ground cable was joined directly to the steel pipe supporting the zinc anode. With this arrangement, current does not pass through the control head, which now serves only as a securing bracket. Although both anodes were of the same general size, the zinc anodes weigh about 145 pounds — approximately double that of the magnesium anodes. Immediately after the modified buoy was returned to the water, its potential was -840 mv. When checked 29 days later, buoy potential was -980 mv. After 51 days, it was -900 mv with a naval vessel secured to the buoy. At the time of the present inspection (132 days after the modification), buoy potential was -930 mv. The condition of the anode at this time is shown in Figure 18.

The potential of System 6C buoy was -730 mv before the buoy was removed for inspection, and that of buoys without cathodic protection was -670 mv. There was very light rust on the studs and nuts which secure the anode assembly. The cathodic protection system was modified to conform with that on System 7C buoy, and immediately after returning this buoy to the water the potential was -890 mv. Ten days later it was -820 mv.

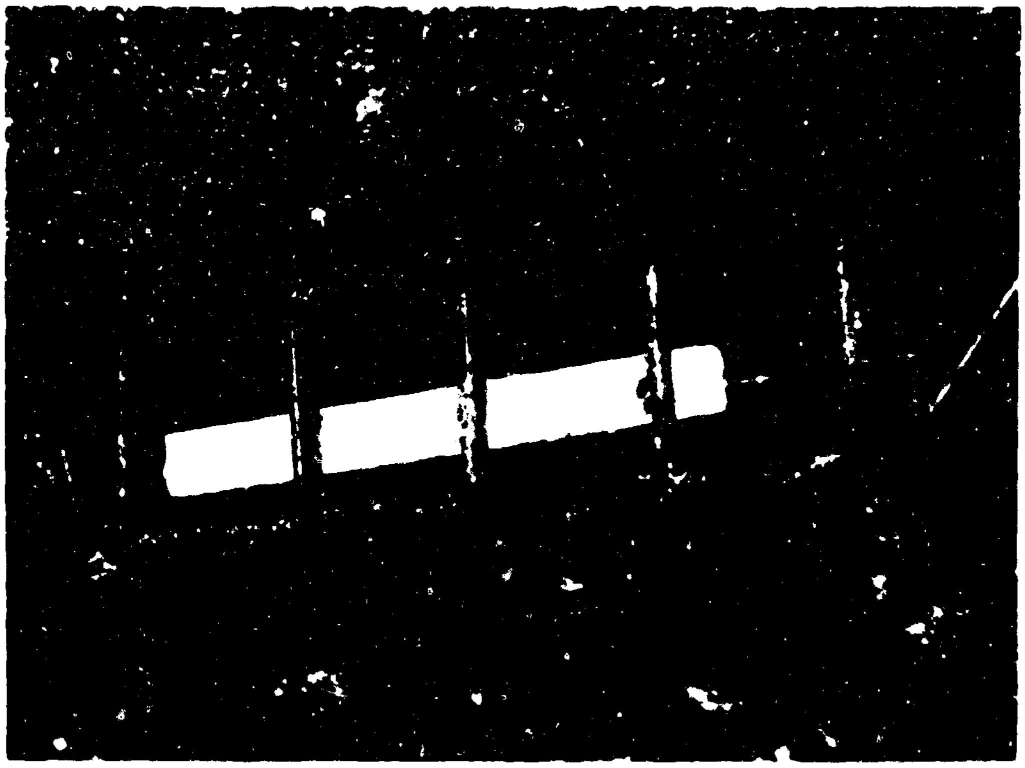

Figure 18. Zinc anode of System 7C after 132 days.

The potential of System 13C buoy was -770 mv before the buoy was removed for inspection. A vessel had struck the lower end of the cathodic protection unit, bending securing brackets, the anode pipe, and the lowest protective steel bar (Figure 19). The brackets and steel bar were straightened, and this magnesium anode was also replaced with a zinc anode. The square of bare steel (Figure 19) previously exposed by wire brushing[3,4] was covered with light rust but was not pitted. There was also light rust on the studs and nuts which secure the anode assembly. Immediately after returning the buoy to the water the potential was -800 mv. The next day it was -820 mv, and 10 days later it was -860 mv.

DISCUSSION

None of the buoy coatings showed significantly greater coating deterioration since the time of the last inspection. Nor had the galvanic corrosion of rivet heads on the Mark I buoys advanced to a very serious extent. Thus, the ratings are very similar to those in the previous inspection report.[4] It appears from these ratings that several of these coating systems, properly applied, can serve better than those previously used on mooring buoys in San Diego Bay. The conditions of the buoy coating systems at the time of each inspection are summarized in Table IV.

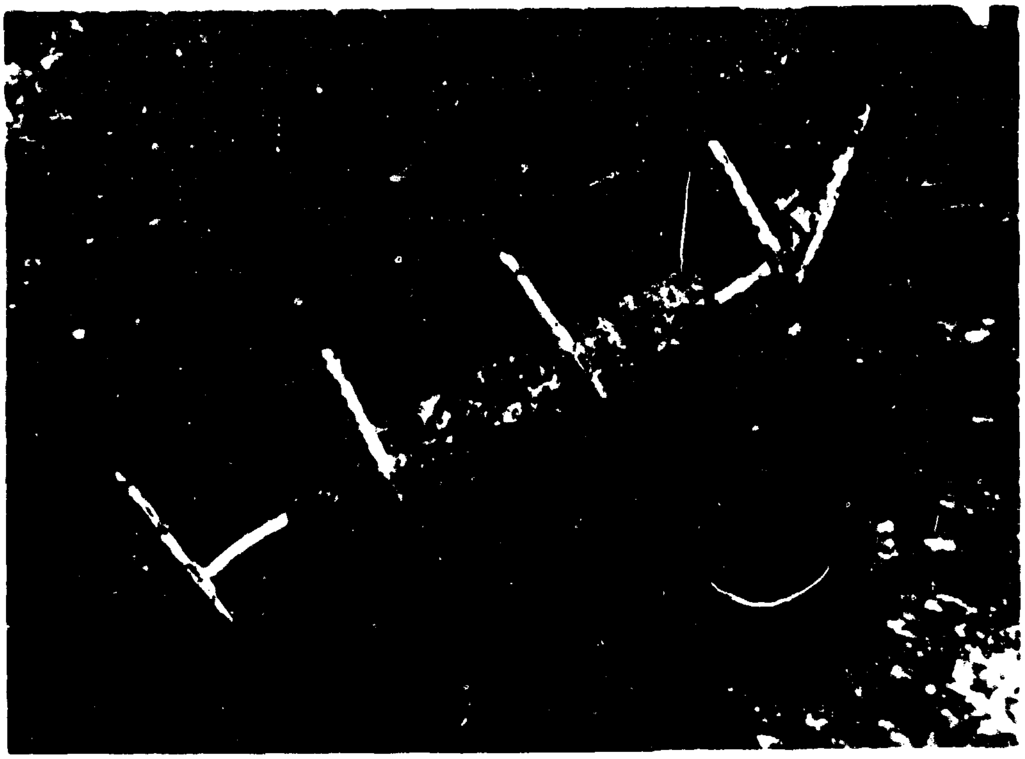

Figure 19. Portion of System 13C buoy showing bent cathodic protection unit and rusted square of bare steel.

Both the shipbottom black (Mil-P-19449) antifouling coatings of Systems 7C and 8, and the vinyl (Mil-P-15931A) antifouling coating of Systems 9 had lost most of their antifouling properties after about 20 months of service on the test buoys. The test panels with these coating systems, however, were still restricting the fouling to a light growth in both harbors. This is consistent with the general opinion that the effectiveness of antifouling paints falls off rapidly after 18 months of service. It should also be noted that the buoys were located in areas where fairly strong currents occur, while both panel exposure locations are relatively quiet areas. Thus, the toxic constituents of the antifouling coatings might be expected to leach more rapidly on buoys than they would on the panels. The marine environment of the San Diego test panels had again changed, as indicated by the presence of shrimp for the first time on these panels. As previously reported,[4] there were no bryozoa on San Diego panels, but they were found on San Diego buoys and Port Hueneme panels.

The coating systems rated good or good-fair on test buoys (Table II) showed slight or no deterioration on test panels after 18 months. In all cases, the coating systems on the buoys had abrasion damage from naval vessels. The white topcoat of all the coating systems had discolored but none seriously. Only those systems with significant deterioration problems will be further discussed in this section.

Table IV. Condition of Buoy Coatings at Time of Each Inspection[1]

Coating System					
1		G	G	G	G
2		G	G	G	G
3		G	F	F	F
4		G	G-F	G-F	G-F
5		G	G-F	F	F
6		G	G	G	G
6C		G	G	G	G
7C	G	G	G	G	
8	E	G	G	G	
9	E	E	G	G	
10		G	F	F	F
11		A	P	P[2]	
12		F	F	F	F
13		G	G-F	G-F	G-F
13C		G	G	G	G

Cumulative Time (months): 6, 12, 18, 24

1/ Ratings:
E = excellent
G = good
F = fair
P poor

2/ Removed after 19 months

In Coating System 3 (epoxy-polyester), much of the polyester topcoats was lost after 1 year of exposure, but even after 2 years the primer was still effective in protecting the buoys and panels from corrosion. The epoxy primer pigmented with zinc chromate is identical to the primer of System 2.

In Coating System 4 (epoxy - coal tar epoxy), although 40 percent of the epoxy seal coat and topcoat had delaminated in the submerged zone of the buoy, the underlying coal tar epoxy and epoxy primer were providing good protection. The same coating system on the panels was in excellent condition after 18 months. Again, no explanation could be found for the difference in behavior of Coating System 4 on the buoy and the test panels.

Coating System 5 (coal tar epoxy-phenolic) had lost sizeable portions of the topcoat in the tidal and submerged zones of both panels, exposing the gray seal coat. This did not occur on the buoy. The coating system was still providing good protection on test panels and fair protection on the buoy.

The blistering and rusting associated with Coating System 10 (high-body vinyl) had not increased appreciably on either the buoy or test panels since the previous inspection.

In Coating System 12 (inorganic zinc silicate - vinyl mastic), large portions of the vinyl mastic topcoat had been lost from the submerged portions of both panels and buoys. But the inorganic zinc silicate continued to protect the steel.

The three newly designed control heads placed on cathodically protected buoys did not raise the buoy potentials into the desired range. Although light rusting occurred on the bare square of steel on the System 13C buoy, the potential produced prevented pitting. Peterson and Waldron[6] found that a low potential may prevent pitting, even though it allows light rusting. The high potentials on the System 7C buoy after the magnesium anode was replaced with a zinc anode indicates that the circuit resistance in the original system was in the control head and not in the ground cable. These potentials also indicate that the zinc was not passivated to any significant extent.

FINDINGS

1. On eight of the test buoys, the coating systems were in good condition; six showed varying degrees of intermediate deterioration.

2. The condition of the coatings had not changed much since the previous inspection.

3. The antifouling coats on the test mooring buoys retained very little antifouling efficacy after 20 months. The vinyl and shipbottom black antifouling coatings on test panels, however, were still retarding fouling after 18 months of exposure.

4. The galvanic corrosion of rivet heads, noted on most of the Mark I buoys in the previous inspection, had not increased significantly.

5. The newly designed control heads, placed on the three cathodically protected buoys in the previous inspection, did not maintain the buoy potential at the desired level.

6. The replacement of magnesium anodes with zinc increased buoy potentials to the desired level and maintained them for the short term herein reported.

CONCLUSIONS

1. Several of these coating systems, properly applied, can serve better than those previously used on mooring buoys in San Diego Bay.

2. The resistance which developed in the original cathodic protection system was in the control head.

ACKNOWLEDGMENT

Mr. A. F. Curry of NCEL made an independent rating of the coated buoys and the San Diego panels. Mr. C. V. Brouillette of NCEL made an independent rating of the Port Hueneme panels.

Appendix A

RATINGS OF BUOYS WITH TEST COATINGS

Coating System 1: Urethane

No. of Days in Service: 787

Overall Condition: Good

Amount of use: Light

Type of Mooring: Bow and Stem

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	—
Chalking	4	4	—
Blistering	N, 10	N, 10	N, 10
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	10	10
Erosion	10	10	10
Rusting, Type I*	9	9	9
Rusting, Type II**	10	10	10
Fouling, amount	—	heavy	heavy
Guano, amount	light	—	—
Structural damage	none	none	none

* Type I - Without blistering
** Type II - With blistering

Coating System 2: Epoxy

No. of Days in Service: 747

Overall Condition: Good

Amount of use: Heavy

Type of Mooring: Bow and Stern

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	—
Chalking	8	8	—
Blistering	N, 10	N, 10	N, 10
Checking	10	10	—
Cracking	10	10	10
Flaking (scaling)	10	10	—
Erosion	10	10	10
Rusting, Type I	9	10	9
Rusting, Type II	10	10	10
Fouling, amount	—	heavy	heavy
Guano, amount	medium	—	—
Structural damage	none	none	dent in steel plate

Coating System 3: Epoxy - Polyester

No. of Days in Service: 747

Amount of use: Heavy

Overall Condition: Fair

Type of Mooring: Bow and Stem

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	–
Chalking	8	8	–
Blistering	N, 10	N, 10	N, 10
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	5*	5*
Erosion	10	10	10
Rusting, Type I	9	9	9
Rusting, Type II	10	10	10
Fouling, amount	–	heavy	heavy
Guano, amount	medium	–	–
Structural damage	fender splintered	none	fender splintered

* Topcoat lost exposing primer

Coating System 4: Epoxy - Coal Tar Epoxy

No. of Days in Service: 787

Overall Condition: Good

Amount of use: Heavy

Type of Mooring: Bow and Stern

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	—
Chalking	8	8	—
Blistering	N, 10	N, 10	N, 10
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	10	6*
Erosion	10	10	10
Rusting, Type I	9	9	10
Rusting, Type II	10	10	10
Fouling, amount	—	light	medium
Guano amount	light	—	—
Structural damage	none	none	none

* Delamination of topcoat and seal coat, exposing coal tar epoxy coating

Coating System 5: Coal Tar Epoxy-Phenolic

No. of Days in Service: 746

Overall Condition: Fair

Amount of use: Light

Type of Mooring: Bow and Stem

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	—
Chalking	8	8	—
Blistering	N, 10	N, 10	N, 10
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	10	10
Erosion	10	10	10
Rusting, Type I	7	9	9*
Rusting, Type II	10	10	10
Fouling, amount	—	medium	medium
Guano, amount	light	—	—
Structural damage	none	none	none

* Rivet heads were badly corroded

Coating System 6: Phenolic Mastic

No. of Days in Service: 745

Overall Condition: Good

Amount of use: Heavy

Type of Mooring: Bow and Stern

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	—
Chalking	6	6	—
Blistering	N, 10	N, 10	N, 10
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	10	10
Erosion	10	10	10
Rusting, Type I	8	9	9*
Rusting, Type II	10	10	10
Fouling, amount	—	medium	medium
Guano, amount	light	—	—
Structural damage	dent in side broken fender	broken fender	dent in steel plate

* Rivet heads were badly corroded

Coating System 6C: Phenolic Mastic

No. of Days in Service: 746

Overall Condition: Good

Amount of use: Light

Type of Mooring: Bow and Stern

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	–
Chalking	8	8	–
Blistering	N, 10	N, 10	N, 10
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	10	10
Erosion	10	10	10
Rusting, Type I	9	9	9
Rusting, Type II	10	10	10
Fouling, amount	–	light	medium
Guano, amount	light	–	–
Structural damage	splintered fender	none	none

Coating System 7C: Phenolic

No. of Days in Service: 599

Overall Condition: Good

Amount of use: Light

Type of Mooring: Free-Swinging

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	–
Chalking	6	6	–
Blistering	N, 10	N, 10	N, 10
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	10	10
Erosion	10	10	8*
Rusting, Type I	9	9	10
Rusting, Type II	10	10	10
Fouling, amount	–	Light	medium
Guano, amount	medium	–	–
Structural damage	none	none	none

* Antifouling only

Coating System 8: Phenolic - Alkyd

No. of Days in Service: 600

Overall Condition: Good

Amount of use: Light

Type of Mooring: Free-Swinging

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	—
Chalking	8	8	—
Blistering	N, 10	N, 10	N, 10
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	10	10
Erosion	10	10	9*
Rusting, Type I	8	9	9
Rusting, Type II	10	10	10
Fouling, amount	—	light	medium
Guano, amount	light	—	—
Structural damage	none	none	none

* Antifouling only

Coating System 9: Vinyl

No. of Days in Service: 622

Overall Condition: Good

Amount of use: light

Type of Mooring: Free-Swinging

Condition Rated	Atmospheric	Splash	Submerged
Color	9	10	–
Chalking	8	8	–
Blistering	N, 10	N, 10	N, 10
Checking	N, 10	10	10
Cracking	N, 10	10	10
Flaking (scaling)	N, 10	10	10
Erosion	N, 10	10	10
Rusting, Type I	9	9	9
Rusting, Type II	10	10	10
Fouling, amount	–	heavy	medium
Guano, amount	light	–	–
Structural damage	none	none	dent in steel plate

Coating System 10: High-Body Vinyl

No. of Days in Service: 713

Overall Condition: Fair

Amount of use: light

Type of Mooring: Free-Swinging

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	—
Chalking	6	6	—
Blistering	F, 2	F, 2	F, 2
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	10	10
Erosion	10	10	10
Rusting, Type I	9	8	9
Rusting, Type II	10	10	10
Fouling, amount	—	medium	medium
Guano, amount	light	—	—
Structural damage	none	fender splintered	none

Coating System 12: Inorganic Zinc Silicate - Vinyl Mastic

No. of Days in Service: 788

Overall Condition: Fair

Amount of use: Light

Type of Mooring: Bow and Stem

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	—
Chalking	8	8	—
Blistering	N, 10	N, 10	N, 10
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	10	5*
Erosion	10	10	10
Rusting, Type I	9**	10	10
Rusting, Type II	10	10	10
Fouling, amount	—	light	medium
Guano, amount	light	—	—
Structural damage	none	none	none

* Topcoat only

** Top edge only

Coating System 13: Saran

No. of Days in Service: 746

Overall Condition: Good-Fair

Amount of use: Light

Type of Mooring: Bow and Stem

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	–
Chalking	8	8	–
Blistering	N, 10	N, 10	N, 10
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	10	10
Erosion	10	10	10
Rusting, Type I	9	9	8
Rusting, Type II	10	10	9
Fouling, amount	–	heavy	heavy
Guano, amount	light	–	–
Structural damage	none	fender splintered dent in steel plate	none

Coating System 13C: Saran

No. of Days in Service: 753

Overall Condition: Good

Amount of use: Light

Type of Mooring: Free-Swinging

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	—
Chalking	10	10	—
Blistering	N, 10	N, 10	N, 10
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	10	10
Erosion	10	10	10
Rusting, Type I	9	9	10
Rusting, Type II	10	10	10
Fouling, amount	—	light	medium
Guano, amount	medium	—	—
Structural damage	dent in steel plate	dent in steel plate	none

Appendix B

RATING OF TEST PANELS AT PORT HUENEME AND SAN DIEGO

Coating System No.	1						2								
Exposure Site	PH			SD			PH			SD			PH		
Panel Zone	A[1]	T[2]	S[3]	A	T	S	A	T	S	A	T	S	A	T	S
General Protection	9	10	10	10	10	10	10	10	10	10	10	10	9	9	10
Chalking	4	—	—	1[5]	—	—	2[4]	—	—	—	—	—	8	—	—
Checking	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Blistering, size	10	10	10	10	10	10	10	10	10	10	10	10	10	6	6
Blistering, frequency	N[5]	N	N	N	N	N	N	N	N	N	N	N	N	MD[8]	D[7]
Flaking	10	10	10	10	10	10	10	10	10	10	10	10	10	8[12]	8[12]
Cracking	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Undercutting	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Rusting, Type I	9[13]	10	10	10	10	10	10	10	10	10	10	10	9	9	10
Rusting, Type II	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Pitting	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Fouling, amount	—	L[9]	L	—	M[8]	H[6]	—	M	L	—	M	H	—	L	L
Fouling, area[10]	—	2	2	—	4	0	—	2	3	—	4	2	—	4	2
1. Plant Area	—	2	8	—	8	8	—	8	8	—	6	8	—	9	4
2. Animal Area	—	10	3	—	5	0	—	3	3	—	6	2	—	4	5
a. Tunicates	—	10	10	—	10	0	—	10	10	—	10	2	—	10	10
b. Barnacles	—	10	8	—	5	9	—	3	8	—	5	8	—	4	9
c. Mussels	—	10	9	—	8	8	—	10	9	—	10	9	—	10	10
d. Bryozoa	—	10	8	—	10	10	—	10	5	—	10	10	—	10	5
e. Hydroids	—	10	7	—	8	8	—	10	7	—	9	9	—	10	8
f. Tube Worms	—	10	5	—	10	9	—	10	6	—	10	9	—	10	9
Overall Rating	10			10			10			10			9		

1/ A = atmospheric zone
2/ T = tidal zone
3/ S = submerged zone
4/ Antifouling top coat only
5/ N = none
6/ H = heavy
7/ D = dense
8/ M = medium
9/ L = light
10/ 0 = 100% fouled; 10 = 0% fouled
11/ F = few
12/ Antifouling and top coat lost exposing p

	3			4						5						6					
	SD			PH			SD			PH			SD			PH			SD		
S	A	T	S	A	T	S	A	T	S	A	T	S	A	T	S	A	T	S	A	T	S
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
—	—	—	—	8	—	—	—	—	—	6	—	—	—	—	—	6	—	—	—	—	—
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
6	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
D[7/]	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
[12/]	10	2[12/]	2[12/]	10	10	10	10	10	10	10	3[16/]	7[16/]	10	1[16/]	0[16/]	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
L	—	L	H	—	L	M	—	M	H	—	M	M	—	L	H	—	M	M	—	L	H
2	—	3	2	—	2	2	—	4	1	—	1	1	—	6	2	—	1	1	—	7	2
4	—	5	9	—	9	9	—	7	7	—	9	9	—	8	9	—	9	8	—	7	8
5	—	6	2	—	2	2	—	6	1	—	1	1	—	7	2	—	2	1	—	8	2
10	—	10	7	—	10	10	—	10	1	—	10	10	—	10	5	—	10	10	—	10	2
9	—	6	8	—	2	8	—	8	10	—	1	9	—	7	9	—	2	9	—	8	9
10	—	10	9	—	10	9	—	9	9	—	9	9	—	10	9	—	8	9	—	10	9
5	—	10	10	—	10	2	—	10	10	—	10	6	—	10	10	—	10	8	—	10	10
8	—	9	9	—	10	8	—	9	9	—	10	6	—	9	9	—	10	6	—	9	9
9	—	10	10	—	10	4	—	10	10	—	10	5	—	10	9	—	10	6	—	10	9
	9			10			10			9			9			10			10		

13/ A few pin holes only

14/ Delamination of primer and top coat exposing zinc silicate coating

15/ Impossible to determine chalking on San Diego panels because of extremely high tide at time of inspection

16/ Loss of top coat exposing gray seal coat

g primer

Continued

oating System No.	7C						8						9								
Exposure Site	PH			SD			PH			SD			PH			SD			PH		
Panel Zone	A	T	S	A	T	S	A	T	S	A	T	S	A	T	S	A	T	S	A	T	S
eneral Protection	9	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	9	8	[illegible]
halking	8	—	—	—	—	—	8	—	—	—	—	—	10	—	—	—	—	—	10	—	—
hecking	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	[illegible]
listering, size	10	10	10	10	10	10	10	10	8	10	10	10	10	10	10	10	10	10	6	2	[illegible]
listering, frequency	N	N	N	N	N	N	N	N	F 11/	N	N	N	N	N	N	N	N	N	F	M	[illegible]
laking	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	[illegible]
racking	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	[illegible]
ndercutting	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	[illegible]
usting, Type I	9	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	9	10	[illegible]
usting, Type II	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	8	8	[illegible]
itting	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	8	8	[illegible]
ouling, amount	—	L	L	—	L	L	—	L	L	—	L	L	—	L	L	—	L	L	—	M	[illegible]
ouling, area 10/	—	6	1	—	5	6	—	9	8	—	6	6	—	4	1	—	7	7	—	1	[illegible]
1. Plant Area	—	7	1	—	7	8	—	9	8	—	6	6	—	4	1	—	7	7	—	9	[illegible]
2. Animal Area	—	9	9	—	6	9	—	10	10	—	7	9	—	9	10	—	7	8	—	1	[illegible]
a. Tunicates	—	10	10	—	10	9	—	10	10	—	10	9	—	10	10	—	10	9	—	10	[illegible]
b. Barnacles	—	9	9	—	6	9	—	10	10	—	9	7	—	9	10	—	7	9	—	1	[illegible]
c. Mussels	—	10	10	—	10	10	—	10	10	—	10	10	—	10	10	—	9	9	—	8	[illegible]
d. Bryozoa	—	10	10	—	10	10	—	10	10	—	10	10	—	10	10	—	10	10	—	10	[illegible]
e. Hydroids	—	10	10	—	10	9	—	10	10	—	10	10	—	10	10	—	9	10	—	10	[illegible]
f. Tube Worms	—	10	10	—	10	9	—	10	10	—	10	9	—	10	10	—	10	9	—	10	[illegible]
Overall Rating	10			10			10			10			10			10			8		

A = atmospheric zone
T = tidal zone
S = submerged zone
Antifouling top coat only

5/ N = none
6/ H = heavy
7/ D = dense
8/ M = medium

9/ L = light
10/ 0 = 100% fouled; 10 = 0% fouled
11/ F = few
12/ Antifouling and top coat lost exposing primer

13/
14/

	10			11						12						13					
	SD			PH			SD			PH			SD			PH			SD		
S	A	T	S	A	T	S	A	T	S	A	T	S	A	T	S	A	T	S	A	T	S
7	9	9	9	9	5	9	10	8	8	10	10	10	10	10	10	9	9	10	10	9	9
—	—	—	—	8	—	—	—	—	—	8	—	—	—	—	—	10	—	—	—	—	—
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
2	10	2	2	10	2	2	10	2	2	10	2	10	10	2	2	10	10	10	10	10	10
M	N	F	F	N	M	F	N	F	M	N	F	N	N	F	F	N	N	N	N	N	N
10	10	10	10	10	7	9	10	6	8	10	4 14/	10	10	2 14/	4 14/	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
10	10	9	9	10	6	10	10	8	8	10	10	10	10	10	10	10	10	10	10	10	10
10	9	9	9	9	6	10	10	8	6	10	10	10	10	10	10	9	9	10	10	9	9
7	9	9	9	10	6	3	10	8	8	10	10	10	10	10	10	10	10	10	10	10	10
7	9	10	10	10	9	10	10	9	9	10	10	10	10	10	10	10	10	10	10	10	10
M	—	L	M	—	M	M	—	L	M	—	M	M	—	L	M	—	M	M	—	L	H
1	—	6	2	—	1	1	—	4	3	—	1	1	—	5	5	—	1	1	—	5	2
9	—	8	9	—	9	9	—	4	8	—	9	9	—	5	8	—	9	9	—	7	8
1	—	7	2	—	1	1	—	9	4	—	2	1	—	8	5	—	1	1	—	7	2
10	—	10	2	—	10	10	—	10	4	—	10	10	—	10	6	—	10	10	—	10	2
7	—	7	9	—	1	9	—	8	10	—	2	8	—	8	10	—	2	9	—	7	9
5	—	10	9	—	10	9	—	10	9	—	9	7	—	10	9	—	7	9	—	10	9
6	—	10	10	—	10	7	—	10	10	—	10	7	—	10	10	—	10	7	—	10	10
8	—	9	9	—	10	8	—	9	9	—	10	6	—	9	9	—	10	7	—	9	9
4	—	10	9	—	10	5	—	10	9	—	10	6	—	10	9	—	10	6	—	10	10
	9			7			8			9			9			10			9		

/ A few pin holes only

/ Delamination of primer and top coat exposing zinc silicate coating

15/ Impossible to determine chalking on San Diego panels because of extremely high tide at time of inspection

16/ Loss of top coat exposing gray seal coat

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1 ORIGINATING ACTIVITY (Corporate author) U. S. Naval Civil Engineering Laboratory Port Hueneme, California 93041	2a REPORT SECURITY CLASSIFICATION Unclassified 2b GROUP	
3 REPORT TITLE Protection of Mooring Buoys — Part V. ˉourth Rating Inspection		
4 DESCRIPTIVE NOTES (Type of report and inclusive dates) Progress report — work done between February 1964 and September 1964		
5 AUTHOR(S) (Last name, first name, initial) Drisko, R. W.		
6 REPORT DATE 4 January 1965	7a TOTAL NO. OF PAGES 50	7b NO. OF REFS 6
8a CONTRACT OR GRANT NO. b. PROJECT NO. Y-R007-08-04-404 c d	9a ORIGINATOR'S REPORT NUMBER(S) TR-355 9b OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
10 AVAILABILITY/LIMITATION NOTICES Copies available at OTS $1.25 Qualified requesters may obtain copies of this report from DDC		
11 SUPPLEMENTARY NOTES	12 SPONSORING MILITARY ACTIVITY BuDocks	

13 ABSTRACT

This is the fifth of a series of reports on the protection of mooring buoys. Fourteen test buoys were given their fourth rating for extent of coating deterioration, corrosion of steel, and fouling. Another buoy was so deteriorated it was removed from test. Exposure periods vary for the buoys. The coating systems on eight of the buoys were in good condition and six showed varying degrees of moderate deterioration. Two sets of thirteen test panels coated with the systems used on the buoys were rated for the third time after 18 months exposure, and results showed a general correlation. Environmental corrosion is supplemented by abrasion of buoys by mooring naval vessels. Three of the buoys were cathodically protected with a sacrificial magnesium anode, a control head, and a zinc anode, united directly to the ground cable, was substituted for the magnesium and potentials were increased to the desired magnitude.

DD FORM 1 JAN 64 1473 0101-807-6800

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Buoys	9					
Protective coatings	10,8					
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